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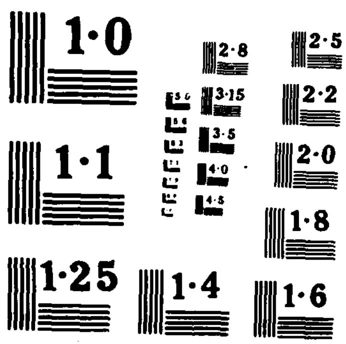
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INTERIM REPORT E-86/05
June 1986
Contracting, Construction, and Acceptance
Testing for Energy Efficient Buildings

Preliminary Recommendations for Improving the Construction and Acceptance Testing of Energy-Efficient Facilities

by
Dale Herron
Dahtzen Chu
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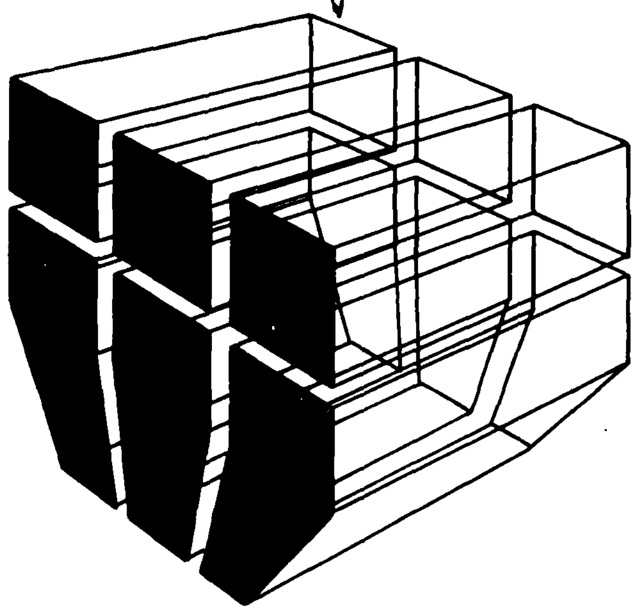

This document describes the preliminary results of a study to recommend changes to the construction phase of the Military Construction, Army (MCA) process. Implementation of these changes would ensure that facility contract documents, the facility construction process, and the resulting facility embody the facility design's energy conservation objectives. The research identified problems with producing energy-efficient facilities within the Corps' current construction process. The operation of the Corps Quality Control/Quality Assurance program was evaluated and improvements suggested. Problems with the energy-effectiveness of Corps of Engineers Guide Specifications (CEGS) were also identified, with improvements suggested for the Air Supply and Distribution Guide Specification (CEGS-15805). Suggested revisions to Section 19, "Testing, Adjusting, and Balancing," of CEGS-15805 were also compiled.

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This document describes the preliminary results of a study to recommend changes to the construction phase of the Military Construction, Army (MCA) process. Implementation of these changes would ensure that facility contract documents, the facility construction process, and the resulting facility embody the facility design's energy conservation objectives. The research identified problems with producing energy-efficient facilities within the Corps' current construction process. The operation of the Corps Quality Control/Quality Assurance program was evaluated and improvements suggested. Problems with the energy-effectiveness of Corps of Engineers Guide

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FOREWORD

This work was performed for the Office of the Chief of Engineers (OCE) under Project 4A162781AT45, "Energy and Energy Conservation"; Task Area A, "New Construction Energy Design"; Work Unit 013, "Contracting, Construction, and Acceptance Testing for Energy Efficient Buildings." The work was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Mr. J. McCarty, DAEN-ECE-E, was the OCE Technical Monitor.

Appreciation is expressed to Michael McCulley, Kevin Frankland and Laura McNellis of USA-CERL and to the staff of the Fort Riley Resident Office, particularly Buck Vannaman, Larry Morgan, Don Crawford, and Joe Staten, for their assistance in determining the actual construction process for MCA facilities. Appreciation is also expressed to Rebecca Bromich and Tom Hoover of the Kansas State University Department of Architectural Engineering for their help with evaluation of the Corps Guide Specifications.

Mr. R. G. Donaghy is Chief of USA-CERL-ES. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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PRELIMINARY RECOMMENDATIONS FOR IMPROVING THE CONSTRUCTION AND ACCEPTANCE TESTING OF ENERGY-EFFICIENT FACILITIES

1 INTRODUCTION

Background

In response to Executive Order 12003[1] and a rapidly increasing utility bill, the U.S. Army has established a goal to have post-FY85 new construction consume 45 percent less energy than FY75 new construction. In response to this goal, the U.S. Army Corps of Engineers has upgraded its design guidance to produce more energy-efficient facility designs. The improved guidance has tightened prescriptive standards, implemented design energy budgets for each facility, and required that rigorous energy evaluations be performed for new facility designs. This upgraded energy design guidance should ensure that new facility designs meet the 45 percent reduction goal.

A facility's actual energy consumption depends not only on its design but also on the quality of its construction and materials, and the operation and maintenance methods used. While energy-conscious facility design is important, the Military Construction, Army (MCA) construction process, including techniques, materials, and equipment, must be able to implement these designs to achieve energy efficiency. If a new facility is not constructed correctly with specified materials and equipment, much of the design effort can be wasted through incorrect execution of the facility's energy-saving features. Thus, there is a need to ensure that the Corps' construction process for MCA facilities (contracting, specification, quality management, and acceptance testing) supports energy-efficiency goals.

Objective

The objective of this study is to recommend revisions to the MCA process to ensure that facility contract documents, the facility construction process, and the resulting facility embody design energy conservation objectives.

Approach

The following steps were taken to carry out the objective of this study.

1. Determine the MCA construction process prescribed in current Army guidance documents.

2. Survey Corps Field Operating Agencies (FOAs) to determine the actual MCA construction process and its effectiveness at delivering energy-effective facilities.

3. Monitor construction to identify problems that reduce the energy-effectiveness of new facilities.

[1]Executive Order 12003, *Relating to the Energy Policy and Conservation* (July 20, 1977).

4. Review current Corps guide specifications to identify energy performance problem areas, and produce example new guide specifications where required.

5. Recommend revisions to the MCA construction process to ensure the energy-efficiency of new facilities.

This interim report summarizes the results of steps 1, 2, and 4 and provides preliminary recommendations for constructing energy-efficient facilities. A report detailing the final results of the study will be available in late FY86.

Mode of Technology Transfer

It is recommended that the results of this study be used to revise the MCA process and the documents that define it. It is further recommended that these study results be used to revise Corps Guide Specifications, particularly those dealing with mechanical and electrical aspects of design and construction.

2 THE MCA CONSTRUCTION PROCESS

Basic Process

Construction of energy-efficient facilities is the responsibility of the Corps District Engineer Divisions. Actual construction is done by construction agents under contract to the Corps District Construction Divisions. The Area/Resident Office manages the construction and is responsible for construction quality consistent with approved engineering drawings and specifications, and for the transfer of finished energy-efficient and maintainable facilities to the customer. All modifications, materials and equipment substitutions, and other changes must be approved by the Corps.

The contract specifications, inspection and acceptance testing procedures, transfer process of the completed project, and the warranty procedure are all important in ensuring that a facility is constructed properly and can be operated correctly. The Corps has established construction quality management regulations for each of these areas. The regulations pertaining to proper construction are described in the following sections.

Quality Control/Quality Assurance

Engineer Regulation (ER) 1180-1-6[2] provides the Corps' general policy and guidance for construction quality management. The regulations define the interrelated roles of the contractor and the government in managing construction quality. The contractor has much of the responsibility for contract compliance. The contractor must establish and implement a Contractor Quality Control (CQC) system for managing and controlling daily operations to comply with contract requirements. His* responsibilities extend to work performed on- and off-site by suppliers, subcontractors, technical laboratories, and consultants. The contractor determines the number and qualifications of quality control personnel. The qualifications and size of the quality control staff must be sufficient to ensure that the contractor's, subcontractors', and vendors' work comply with the contract.

The Corps ensures that the contractor's quality control is properly executed through its Quality Assurance (QA) program. The Corps' responsibilities include: (1) reviews of plans and specifications for constructability, biddability, and operability; (2) plan-in-hand site reviews; (3) coordination with using agencies or local interests; (4) establishment of performance periods and quality control requirements; (5) field office planning; (6) reviews of quality control plans; and (7) enforcement of contract provisions and acceptance of completed construction. The Area/Resident Engineer is responsible for having and maintaining an adequate force of qualified inspectors to inspect all construction work under his/her supervision.

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[2]Engineer Regulation (ER) 1180-1-6, *Quality Management* (Office of the Chief of Engineers [OCE], 24 April 1978).

*The male pronoun is used to refer to both sexes.

Contract Specifications

The contract specifications are important in ensuring that a project is constructed properly. Besides the design drawings, the specifications are normally the only other determinant of a design's energy-efficient features, since only what is specified will be built. The contractor and the Area/Resident Engineer rely on the contract specifications for proper construction and proper inspection. The contract specifications are based primarily on Corps guide specifications. Engineer Pamphlet (EP) 415-1-261[3] states that the contract specifications, government reference specifications and documents, and commercial reference specifications and documents should be in the contractor's library. All of these publications should be available for use by the contractor's quality control inspectors. Corps personnel are to help the contractor obtain reference specifications. Some District's construction management manuals state that the Resident Office is required to maintain some of the major specifications and documents.

Testing and Inspection

Testing

The amount of acceptance testing varies and is determined by the specifications. In general, the contractor is responsible for all testing, but the Districts must conduct unannounced QA tests at the jobsite to assure acceptability.

The Corps has no standard regulations on what tests are required. Actually setting up a standard list of tests is not practicable because the testing procedures and the number of tests to be performed varies with the project type and the materials and equipment used. The tests that are specified in the specifications are the only ones that will be done, and it is the responsibility of the District Engineer Division to assure that the appropriate tests are specified.

Contractor Inspections

Inspections to maintain contract compliance occur throughout the project. The contractor's QC plan includes the "three-phase" or "three-step" inspection process: (1) preparatory inspections, (2) initial inspections, and (3) followup inspections. Preparatory inspections are held before each phase of work to ascertain that documentation is complete, materials and/or equipment are on hand and approved, and the workers understand what they need to know about the work phase. Initial inspections are conducted upon completion of a representative portion of the work to check for workmanship and contract compliance. The contractor's quality control representatives conduct daily followup inspections to assure continuing compliance with contract requirements. The Corps participates in the three-phase inspection process as appropriate, and is also responsible for phased acceptance inspections of completed work for in-process payment. At the completion of all work or any increment thereof as stated in the specifications, the contractor conducts a completion inspection and develops a "punch list" of nonconforming items. This list identifies deficiencies and establishes dates for their correction. A second completion inspection is conducted later to confirm that all corrections have been made. If corrections are not made, the deficiencies are reviewed by the District Engineer Division for possible legal action.

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[3]Engineer Pamphlet (EP) 415-1-261, *Construction Inspector's Guide* (OCE, November 1981).

Corps Inspections

The Corps monitors the contractor's progress through construction and the QC program. Corps QA personnel participate in the contractor's three-phase inspections as necessary, and also perform joint inspections, beneficial occupancy inspections, prefinal inspections, and final inspections. Joint inspections, which occur during construction, are done by the Area/Resident Engineer and the using service. They enable inadequacies, especially in design, to be noticed before the project is completed. Beneficial occupancy inspections, which are performed when all or part of a facility will be occupied prior to its completion, are made jointly by the Area/Resident engineer, the using service, and the contractor. Deficiencies are recorded with the understanding that the customer will accept the facility with the deficiencies and that the contractor will correct them within a specified period. Final payment shall not be made and the construction contractor's bonding company shall be notified of such deficiencies. The bonding company shall also be provided with the schedule for correction of deficiencies prior to acceptance of the facility by the customer (signing of DD Form 2354). Pending acceptance, the Corps will retain title and fund all required maintenance of the facility to prevent degradation. The prefinal inspection, which occurs when work is mostly complete and prior to acceptance, ensures that the contractor has complied with the contract requirements. If no deficiencies or only a few minor ones are found, the prefinal may be considered the final inspection. The customer is the sole authority as to the classification of a minor deficiency. If a final inspection is necessary, a date will be established after the prefinal inspection.

Transfer of Completed Work

Upon completion of construction, facilities will be transferred to the user following the procedures in ER 415-345-38.[4] Only facilities with satisfied contract requirements or only minor deficiencies that will not interfere with the designed use are to be accepted for transfer. Once the construction completion date is determined, the Contracting Officer--usually the Area/Resident Engineer--will notify the contractor, customer, and appropriate command to arrange a joint inspection of the completed facilities. Prior to the inspection, the Contracting Officer will prepare the following materials from the appropriate organization for transfer to the customer after inspection:

1. DD Form 1354, Transfer and Acceptance of Military Real Property. (Area/Resident Engineer)

2. DA Form 2877, "Real Property Record" or a real property list for all affected facilities. (District Construction Division)

3. Comprehensive operating and maintenance instructions for each operating piece of equipment, plus record sets of wiring diagrams, piping layouts, valve charts, valve tags, color codes for wiring and piping, and spare parts catalogs. (District Engineer Division)

4. Spare parts and tools, where required by the contract. (District Engineer Division)

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[4] ER 415-345-38, *Transfer and Warranties* (OCE, 15 May 1980).

5. List of equipment covered by warranty under the terms and conditions of the contract, including the warranty periods, and the names, addresses, and telephone numbers of the prime contractor, subcontractors, equipment suppliers, and manufacturers. (District Engineer Division)

6. Warranty documents. (Area/Resident Engineer)

7. Copy of the test results for mechanical and electrical systems and/or equipment stating that the systems have been tested in accordance with the contract documents. (District Engineer Division)

8. All specialized keys, handles, and tools required for operating building equipment, and tag keys for each lock, showing lock schedule data, building number, or designation. (Area/Resident Engineer)

9. All leases and contracts pertinent to the facilities being transferred. (District Real Estate Organization)

The joint inspection and transfer procedures include a search for deficiencies, a review of as-built drawings, project cost, and data for real property cards. Deficiencies that are found will be listed on the reverse of DD Form 1354, but should not delay transfer. Acceptance is within the purview of the customer and the MACOM.

Following the joint inspection and transfer, the Contracting Officer will determine whether the deficiencies found are contract deficiencies, or are not within the scope of the contract documents. The Contracting Officer is to provide for correction of the contract deficiencies. He is also supposed to notify the using service of deficiencies that are not covered, and inform them of actions to be taken. The District is responsible for all deficiencies due to construction, and will fund and schedule corrective action prior to DD Form 1354 transfer.

Within 90 days after transfer of the completed facility, the Contracting Officer should furnish the following to the using service:

1. "As-built" drawings, including the project site plans

2. Final approved shop drawings

3. Construction contract specifications, including modifications

4. The design analysis

5. The make and model number of each major piece of equipment, with spare parts list and manufacturers' catalogs for the equipment

6. Status report on correction of deficiencies not within the scope of the construction contract.

After completion of the contract, the Area/Resident Engineer prepares and submits to the District a Certificate of Completion, certifying that the final inspection is finished, that all required work has been done in accordance with the contract, and that the Area/Resident Engineer has accepted the facility and transferred it to the using service. The date the contract was completed, date of acceptance by the Area/Resident Engineer, date of transfer to the using service, and the date(s) that any deficiencies were corrected should also be included.

A report should be prepared each month to OCE identifying oustanding deficiencies. If the deliverables have not been provided within the 90 day period, the District will notify the MACOM and provide a firm schedule for completion.

Warranty Procedures

After transfer to the using service, the Corps assumes primary responsibility for evaluating and correcting defects for 1 year. However, it is generally up to the using service to discover deficiencies and correct them under terms of the guarantees.

Six months after transfer of the completed facility, EP 415-1-260[5] and ER 415-3-11[6] require inspections to detect and correct deficiencies and to identify design inadequacies and areas with potentially high maintenance and operating costs. However, correction of major defects that affect operations, habitability of living spaces, life safety, or the physical safety of the facility should not be delayed. The actual time of these post-transfer inspections is often dependent on the availability of manpower and may not always be done on schedule because of staffing shortages.

Most post-transfer defects are found by the user or Facilities Engineer (FE). It must then be determined whether the defect is a result of troop abuse, improper operation or maintenance, or a design or construction error. Defects caused by troop abuse or by improper operation or maintenance are the FEs responsibility. Defects for which the contractor is responsible should be resolved according to contract stipulations.

It is not always clear who is responsible for the defect(s). If the contractor is called for a defect that was not his fault, he may fix it, but he will also submit a bill. Often, problems are the result of incorrect operations or lack of maintenance, when shop people have not been trained properly or were not told to maintain the equipment. In some cases, personnel were trained, but were later transferred.

ER 415-345-38 lists procedures to follow for typical defects. These include procedures for defects not covered by contract clause or warranty:

1. Construction for the Army on MCA-Funded Projects:

a. Construction Defects Covered by a Contract Warranty: Normally, the FE will initially identify and evaluate defects not discovered prior to acceptance by the government. Depending on what is most appropriate for the particular case, either the FE or the District will make initial contact with the contractor, vendor, or manufacturer to obtain correction. If the problem is relatively minor and/or the vendor or contractor is local, it will usually be more expedient and practical for the FE to make the initial contact. If the vendor or contractor is not local, if the problem involves major equipment, or if complications develop, the defect will be referred to the District for correction. Problems that cannot be resolved by the FE will be referred to the District for resolution. Additional funds normally will not be required to correct these defects.

b. Design Defects Covered by an A/E Contract Clause: Upon identification of design defects, the District will obtain correction by the most expedient means, and

[5]EP 415-1-260, *Resident Engineer's Management Guide* (OCE, 15 October 1973).
[6]ER 415-3-11, *Feedback Information (Exempt Reports, Para 7-2u-AR 335-15)* (OCE, 14 August 1981).

where appropriate, take action to recover costs under applicable contract clauses. The District will arrange for any additional funds required for immediate and full correction.

c. Design and Construction Defects Not Covered by a Contract Clause or Warranty: Upon identification and evaluation of these defects, the District will correct them by the most expedient means, using appropriate available project funds or by requesting additional MCA funds through Corps channels.

d. Defects in Government Property Installed by the Construction Contractor: Procedures similar to those explained in 1a above will be used when a government furnished property (GFP) item is covered by warranty. For items not covered by warranty, or for those whose warranty has expired before the end of the first year after facility transfer, the District will obtain correction by the most expedient means, using appropriate available funds or by requesting additional MCA funds through Corps channels.

2. Construction for Non-MCA-Funded Projects: The same procedures will be followed as for MCA-funded projects, except that the user must provide additional funds for Corps correction of defects listed in 1c and 1d above.

3. Construction Performed for Agencies Other Than the Army: Procedures will be similar to those explained above for MCA-funded projects, unless there is a separate agreement with the agency. In any case, the user must provide additional funds to correct defects listed in 1c and 1d above.

4. The Contracting Officer will take all necessary actions to recover from the contractor the cost of defects for which the contractor or design firm should be held responsible. Appropriate MCA funds will be requested from Department of the Army Headquarters (HQDA), and reimbursable funds will be requested from the customer.

5. Neither acceptance of a facility by the government nor the end of the 1-year warranty period terminates the contractor's, manufacturer's, or supplier's liability for any piece of equipment if there are latent defects or mistakes so gross that they may amount to fraud.

3 PROBLEMS WITH ACHIEVING QUALITY MANAGEMENT

Chapter 2 described ideal Corps regulations and procedures for ensuring quality over the entire construction process. Although all Corps field offices follow these regulations (sometimes in modified form), it is uncertain whether they result in quality facilities. A Blue Ribbon Panel on Management of Construction Quality in the U.S. Army Corps of Engineers was appointed to find methods of improving the quality of the Corps' construction, effectiveness of contractor's quality control, and the level of the Corps' quality assurance administration. The panel, which looked at quality in all phases of the construction process, found that the Corps does not have a widespread problem with construction quality. However, it did find that there are shortcomings in Corps construction management which allow delivery of facilities that do not meet contract requirements. These defective facilities are not always the result of poor construction quality; they can also be caused by other defects. For example, the Corps' testing programs for new technology options (e.g., solar energy systems; EMCS; controls for heating, ventilating, and air conditioning; and heat-recovery incinerators) appear inadequate; a number of recently completed high-technology projects have operational difficulties. Most newer technologies require nonconventional construction methods, but QA personnel often do not have enough specific knowledge of these technologies to ensure quality installation. Also, after installation is complete, FEs have difficulty defining requirements for manning, training, and operation and maintenance for these newer technologies. Thus, it is apparent that the testing programs for construction involving many new techniques are not sufficient to allow quality facilities.

The same deficiencies also occur during construction of energy-efficient mechanical systems. A system may be designed correctly, and its construction can conform completely to the contract documents, but the final product still may not be of acceptable quality. This is because testing and balancing of the mechanical system is an area where current Corps specifications do not provide sufficient coverage. Few acceptance tests treat the mechanical system as an integrated whole. Neither FEs nor Corps QA personnel are certain that they are getting the capabilities for which they contracted. Operation and maintenance of a completed system can be another problem area because of inadequate instructions or lack of personnel.

Clearly, a quality product is not always provided by plans and specifications that may appear to delineate all details required for proper construction. The Corps' in-house knowledge is often not sufficient to recognize these inadequacies until it is too late in the process. Coordinating problems and transferring solutions from "lessons learned" in design, procurement, construction, and operation among the Corps of Engineers Divisions, Districts, and FEs must be increased to improve the quality of finished facilities. A step in this direction has been taken with the inclusion in the FY86 criteria update program of a new separate specification addressing HVAC testing and balancing.

Findings of the Blue Ribbon Panel

This section summarizes the findings of the Blue Ribbon Panel on overall quality management in Corps construction projects. The list is followed by findings of a limited survey of Corps field offices conducted by the U.S. Army Construction Engineering Research Laboratory (USA-CERL).

1. Although the Corps does not have a widespread construction quality problem, there are shortcomings in its construction management. This sometimes results in

facilities being delivered that do not meet contract requirements. Also, poorly conceived designs are sometimes a problem.

2. Although the Corps delivers quality projects, quality does not drive the engineering-construction system. Quality is achieved within management-emphasized constraints to meet financial goals, award contracts, and stay within budget ceilings and scheduled milestones.

3. Area/Resident field staffs show a lack of uniformity in, as well as a lack of understanding and appreciation of crucial quality assurance responsibilities.

4. Feelings of defeatism, powerlessness, and frustration pervade field engineers. Many construction field personnel feel that their grade levels are not commensurate with their responsibilities, that their suggestions for improvement are ignored, and that they are not backed in major decisions by their management, legal counsel, and personnel offices.

5. The current Contractor Quality Control/Quality Assurance (CQC/QA) system has a sound basis, but its operation needs improvement. Field belief in the current CQC/QA process varies. Many field engineers feel that (a) the Corps hierarchy does not believe in the CQC/QA process, (b) there is little shared understanding within management and the field of the rationale and purpose for CQC, (c) there is little differentiation between what is a verifiable deficiency and what is not, (d) the term QA has no visible status in the formal Corps organization, and (e) there is poor "lesson-learned" feedback within the Corps' construction system.

The panel divided construction quality issues into several problem areas: (1) customer/user satisfaction, (2) the CQC/QA and supervision and inspection process, (3) personnel resources, (4) construction-engineering interface, and (5) organization, management and administration problems. The following sections list the panel's findings for each problem area.

Customer/User Satisfaction

1. The most frequent customer complaints center on failure to:
   a. Deliver a facility on schedule
   b. Ensure the facility's operability and maintainability
   c. Provide comprehensive O&M documentation
   d. Train O&M personnel in the use of facility components
   e. Provide timely correction of deficiencies.

2. Customers/users are generally satisfied with the quality of Corps products, but there is room for improving both design and construction management.

3. Customer/user dissatisfaction most frequently centers on project turnover, early operations stages, contract administration, financial management, and two-part change orders.

4. The Corps needs to improve techniques to solicit, use, and document user input throughout project development.

CQC/QA and Supervision and Inspection Process

1. The CQC/QA system is not well understood by Corps office staff, field staff, and contractors.

2. The Area/Resident Engineer is the crucial person in providing quality products, but his QA role is little understood and not well supported.

3. The paperwork burden on the Area/Resident Engineer caused by unessential submittals and administrative support demands must be reduced if the Corps is to maintain quality.

4. Most QA programs are informal and are frequently inadequate for new technology. Few Resident offices have either a well-defined or a standard procedure for QA administration across all contracts.

5. The Corps' field staff needs better standards and guidance on how much QA is expected. Statements made in the CQC plan are often general, and not verifiable by QA personnel. They need to staff and organize vigorous surveillance over construction processes and parameters that are not easily verifiable.

6. CQC/QA needs renewed emphasis and recognition by top management.

7. There is little feedback exchange on contractor's "lessons-learned" in new technology.

8. The Corps needs better tools for acknowledging good contractor performance.

Personnel Resources

1. The Corps has a minimal QA staff in some areas, and could lose inspection expertise in the future.

2. QA inspectors must be more versatile than before.

3. QA personnel must now devote more time to paperwork, with less time available to spend in "on-site" QA monitoring.

4. The Corps sometimes does a poor job in early staffing. Consequently, QA staffing also suffers early, when it is most needed.

5. Career programs for field inspectors must be improved.

6. There is no uniform definition of the essential QA duties.

7. Training systems for field personnel need major improvements.

Engineering-Construction Interface

1. Documentation and interaction are inadequate between engineering and construction on projects that are "rushed" into construction.

2. Engineering-construction conflicts are caused by the rush to push out contracts.

3. There are often adversarial relationships and parochialism within the engineering and construction divisions.

4. There is insufficient cross-training and joint experience among professionals in the engineering and construction divisions.

5. There are opportunities for better joint participation between the engineering and construction divisions, but they are insufficiently used.

6. Formal and informal communication among engineering division and construction division personnel must be improved.

7. Perceived grade-level disparity among engineering and construction personnel is a factor contributing to friction between the two divisions.

Organization, Management, and Administration

1. Field construction personnel often feel powerless and frustrated because they think they are not listened to by the hierarchy or supported by legal counsel and the personnel office.

2. Corps administration and organization often work counter to Area/Resident Engineer QA efforts.

3. QA is not highly visible within the formal Corps organization and in the Area/Resident Engineers' job descriptions. Only a few Divisions or Districts have a QA element. Consequently, QA is done less formally among Area/Resident Engineers, staffs, and contractors, and very few QA plans ever emerge.

4. Resident offices need to upgrade office procedures and data processing equipment to cope with increasing administrative requirements.

5. The Corps' Area/Resident engineers are overburdened with demands for document reporting, contract administration, change orders, performance appraisals, etc., which detract from QA.

6. Opportunities for contracting out administrative support services need to be explored.

7. Technology transfer of ways to improve CQC/QA techniques are weak. The ability of the research and development community to "sell" products that may assist QA and the willingness of the field to accept the product must be enhanced.

8. The Corps needs better guidance on how to address impact costs related to major modifications.

9. The Corps must improve its methods of recording and sharing organizational successes and failures. Each time a new assignment arrives, one of the first actions should be to settle on a management philosophy, and to develop an organizational structure to execute the program or project. Currently, as each of these special tasks is completed, the people move on and records of successes and failures disappear.

USA-CERL Survey

To ascertain current practices for construction quality control, USA-CERL contacted a number of districts and field offices (Appendix A). Personnel were interviewed by phone and then by a letter "survey" about construction quality and procedures used. The letter survey asked the same questions used in the phone survey, but allowed time to prepare a more extensive response. The survey requested information on six areas of interest:

1. Quality control and quality assurance procedures, including division of responsibilities, inspection procedures, and testing procedures

2. Procedures for transferring completed facilities and the documentation required

3. Procedures for correcting deficiencies and delegating responsibilities

4. Length of warranties and enforcement responsibilities

5. Procedures used by Districts to produce specifications for new projects

6. How extensive a specifications library is maintained for reference purposes.

The amount of information obtained from the various offices ranged from none (possibly due to understaffing) to very detailed responses. None of the respondents claimed to have serious problems with construction quality, but most felt that there was room for improvement. The information provided was reviewed and grouped into the six areas of interest. The following paragraphs summarize the results.

Quality Control and Quality Assurance Procedures

In general, quality control and quality assurance procedures generally follow those described on p 7. For quality management, it appears that most Districts either follow the requirements of ER 1180-1-6 or have their own regulations that are based on ER 1180-1-6. The Districts provide these regulations to their field offices, but some field offices make up their own.

It is questionable whether quality management is actually implemented correctly. According to the Blue Ribbon Panel, the Corps has not strongly emphasized quality assurance in the past. Few resident offices have well-defined or standard QA procedures for all contracts. The panel also found that the CQC plan was written and submitted mainly for contract compliance, and rarely used by the contractor in the field.

The plans, specifications, and testing program for mechanical systems using new technologies are often inadequate. Some sources stated that testing is generally done for materials rather than equipment. This inadequacy must be addressed to prevent the incorrect operation and/or use of inadequate or incorrect equipment and/or systems.

Transfer Procedures and Documentation

Each District questioned had its own regulations for transfer procedures, but all were based on ER 415-345-38. The amount of detail varied, with some Districts requiring just DD Forms 1354 and 2877, and others also requiring the additional information specified in ER 415-345-38.

Deficiencies

Districts and field offices presumably follow the procedures listed in ER 415-346-38 for correcting deficiencies; however, this was not spelled out. Responsibility is split between Area/Resident Engineers and the using service, depending on the practice of the District or field office. Followup inspections at 4- and 9-month periods after project completion appear to be standard.

Warranties

The standard warranty period is 1 year from the date of acceptance. The user is usually responsible for enforcing the warranty, although the field office will become involved in case of difficulties with the contractor.

Production of Specifications

All field offices that responded to the survey use Corps guide specifications provided by their respective Districts. The specifications are then edited and adapted to the individual design. In cases where no guide specifications are available or suitable, original specifications are written.

A problem that often occurs is that change notices or updates are not used because there are so many of them and/or because there are staffing shortages at the District level. This results in out-of-date guide specifications being used. A related problem occurs when the guide specifications are greatly altered by private AEs designing for the Corps. As a result, buildings with identical designs can have significantly different specifications.

Reference Library

The District usually keeps a comprehensive reference library. Field offices are supposed to have ready access to these libraries. These libraries constantly receive updates for both the various reference specifications and Corps guide specifications. A problem is that a District may not have adequate staff or time to keep track of numerous specifications as well as the constant supply of updates and deletions. Field offices have neither the capability to maintain an up-to-date reference library nor enough space to keep the specifications. Thus, field offices are often unable to answer contractors' questions or problems with referenced specifications because they do not have the specifications themselves.

Additional Field Comments

Several Districts and field offices provided additional comments on quality management in their survey responses. These comments revealed that their projects were not always problem-free. The following sections summarize these comments by problem area.

Customer/User Satisfaction

1. Users prefer more inspection (i.e., there is some dissatisfaction with the current system).

2. Maintenance problems with mechanical systems often occur because the people originally trained to operate them are transferred.

CQC/QA and the Supervision and Inspection Process

1. QA personnel are sometimes too dependent on the contractor's QC reports, and fail to perform adequate quality assurance inspections and testing.

2. More quality assurance is needed at the submittal and preparatory inspection stages.

3. Performance tests are not always specified for equipment. There is a question about whether they should be done by the contractor, the Area/Resident Engineer, or the District.

4. Use of acceptance testing is determined by specifications, but is either not always done, or is not done consistently.

5. Post-completion warranty inspection problems include lack of written notice to the contractor and poor recordkeeping of actual calls and work performed.

6. Deficiencies are sometimes not corrected when discovered, but rather left as "punch list" items. This may prolong job completion and closeout.

Personnel Resources

1. CQC personnel are sometimes ineffective, incompetent, or unscrupulous. They sometimes do not comply with contract requirements (e.g., QC plans are not timely or complete, required tests and inspections are not made, and deficiencies are not corrected).

2. QA personnel do not have enough training, and there is often not enough staff to perform all required duties.

3. Corps field inspectors are often not familiar with Corps contract specifications and do not know what is required.

4. The Area/Resident Engineer has too many QA reports to keep track of, and the reports are too long (20 to 100 pages each).

5. Personnel who maintain equipment are not always trained properly.

Engineering-Construction Interface

1. Deficiencies occur for different reasons at different installations; at some, they are due to improper specification of materials or equipment rather than workmanship, while at others, improper methods rather than materials are the cause.

2. Construction problems have occurred when the drawings do not correlate with the specifications, resulting in confusion for the contractor and field personnel.

3. Lack of coordination between designers for different projects located on the same site has resulted in unnecessary delays because redesign was required to keep the projects from interfering with each other.

4. The Corps is not automatically getting energy-efficient designs for its new facilities.

Organization, Management, and Administration

1. A common, but short-sighted, aim is to get the project done with minimum work. This leads to oversights and deficiencies.

2. Warranty enforcement is sometimes difficult because it is hard to tell if the problems are caused by operation and maintenance deficiencies, incorrect design, or even whether they are covered by warranty.

3. The contract takes longer to complete if there are problems with contractors that must go through administrative channels.

4. Contractors try to avoid paperwork; they do not record discussions or file deficiency reports.

5. Occupancy before completion makes it difficult to get timely completion of work, because there is no threat of liquidated damages.

6. Circulation of repeat deficiencies lists is poor.

7. Enforcement of the warranty after the project has been completed and the contractor paid off depends on the contractor's "good will" or his desire to work on future Corps projects. Warranty work is often not a high-cost item, so legal action is not practical.

8. The Corps needs to provide the MACOM and ultimate user their actions on comments provided during project design evaluation on a timely basis.

4 EFFECTIVE CONTRACT SPECIFICATIONS

The Corps uses contract specifications to describe specifically what materials are to be used in a facility, how they are to be installed, and how the contractor and the Corps will verify a particular component's performance. Contract specifications have often been a source of frustration for Area/Resident Engineers and contractors. Contractors have difficulty interpreting exactly what the specification permits them to do; Area/Resident Engineers have problems determining how to review the contractor's work according to the specification and how to enforce the specification. Poorly written specifications can result in the use of inferior materials or lead to poor construction because of inadequate inspections.

Contract specifications are typically prepared by the District designers or their Architect/Engineer design contractors using Corps of Engineers Guide Specifications (CEGS) as a baseline. These specifications are then edited as required to match specific facility requirements.

As emphasis on energy efficiency increases, complexity of the facility designs increases correspondingly. This is particularly true of mechanical systems in new facilities. The increased complexity of design makes the mechanical contractor's job especially important. The system will maintain building comfort and minimize energy consumption only if it uses the correct components, is installed correctly, and is adjusted to perform as designed. This information is given in the mechanical system specifications for a new facility. To help determine if the Corps' current specifications provide guidance to maximize the facility's energy effectiveness, USA-CERL reviewed one of the mechanical system CEGS in detail.

Review of Air Supply and Distribution Guide Specification

The Air Supply and Distribution Guide Specification (CEGS-15805)[7] was selected for review for several reasons: (1) it is used in a significant number of facility specifications produced by the Corps, (2) the topic covered is extremely important to the facility's energy effectiveness, and (3) the Corps completely revised it recently (August 1984).

USA-CERL used the following procedure to evaluate the specification:

1. Compare it with similar specifications from private industry and other governmental agencies.

2. Evaluate the extent to which the Districts use it to produce actual specifications for specific facilities.

3. Critique each section, paragraph, and all wording for clarity, continuity, conflict, and repetitiveness.

The evaluation revealed many positive areas, but also some areas of concern. The specification is very comprehensive, since it is intended to generally cover all types of

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[7]Corps of Engineers Guide Specification (CEGS) - 15805, *Air Supply and Distribution System (for Air-Conditioning System)* (OCE, January 1985).

air distribution systems. This tends to make the specification lengthy, and the complexity of some statements are such that field personnel who are not engineers may have difficulty understanding them.

CEGS-15805 was compared to similar specifications produced by other government agencies. Generally, the Corps specification was easier to read and understand. However, compared to private-sector specifications, the Corps document is very complex. Private specifications tend to be more limited in scope and therefore less complicated. They generally refer to a specific product and may use an "or equal" designation. This can give suppliers and contractors a much better guide for material and equipment selection than Corps specifications, which refer to performance standards for the material. On the other hand, "or equal" designations can also cause problems in determining how "equal" one product is to another, and it is current Corps policy not to use this method of product specification.

When CEGS-15805 was compared to actual project specifications being produced by the Corps Districts, many areas of the specification were found to be changed or rewritten. Several sections of actual specifications were found to vary from the guide:

1. Project specifications included a section on general requirements for drawings.

2. Project specifications on ductwork were rewritten.

3. Required sections of the guide specification were omitted from the project specification.

4. A section on multizone units was added to the project specification because it is not included in the CEGS.

A detailed critique of CEGS-15805 revealed several problems. One major area of concern is the referral to specifications or standards produced by 22 other agencies. When these are added to the standards referenced by the rest of the contract specifications, the total number of referenced specifications can be very great. Most Corps field operating agencies, contractors, and suppliers will have great difficulty gaining access to all the required standards. Including the required information in the guide specification can reduce the number of references to other standards, but it will also increase the bulk of the specification. The task of updating the guide specification to reflect updates in the reference specifications can also be made more difficult and time consuming. Not surprisingly, there is no easy solution to this problem.

Another major problem is that CEGS-15805 contains very little information on how air distribution systems are to be tested and balanced. For example, Section 19 contains only general information on testing, adjusting, and balancing (TAB). If the Corps is to produce energy-effective facilities, a comprehensive TAB guide specification is required. The specification should be written so that when the District designers or their contracted design agents produce the project specification, they can easily identify specific areas that apply to their design. Since it is unrealistic to expect each Area/Resident Office to have a TAB expert on the staff, a detailed TAB specification must be provided to ensure thorough verification of equipment/system operation and efficiency. The District designers and the Area/Resident Office should have, as a minimum, the two following publications for reference purposes: "NEBB Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems" and "AABC National Standards for Field Measurements and Instrumentation - Total System

Balance."[8] Finally, if a building's mechanical systems are to be energy-efficient, the TAB specification must be written so that the Area/Resident Engineer can ensure complete compliance from the mechanical contractor.

USA-CERL has completed an initial draft of a revised Section 19 of CEGS-15805 that incorporates the requirements discussed above. The example revision describes in detail the required TAB. Appendix B provides the complete text of the example revision.

Other sections of CEGS-15805 were also examined by USA-CERL. General and specific suggestions for improving the overall document are provided in Appendix C.

Other Guide Specifications

A general review of other CEGS revealed similar problems. All the mechanical and electrical guide specifications need revision to include detailed acceptance testing procedures for all aspects of the systems. With the present specifications, the construction contractor has little indication of how the installed equipment is to be tested, and the Area/Resident Office has little indication of how to verify whether the equipment has been installed and is operating properly. Further research is needed to produce acceptance testing procedures that ideally are accurate, easy to perform with minimal training, and can be acceptable to both industry and the Corps. Some of these goals are contradictory, and whether or not it is possible to develop procedures that can satisfy all these goals has yet to be determined.

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[8] *NEBB Procedural Standards for Testing, Adjusting, and Balancing Environmental Systems* (National Environmental Balancing Bureau); *AABC National Standards for Field Measurements and Instrumentation—Total System Balance* (Associated Air Balance Council).

5 CONSTRUCTION MONITORING AT FORT RILEY, KANSAS

Two construction projects were selected for monitoring to further define problems in obtaining energy-effective facilities with the current MCA construction process. The projects selected were 1984 MCA Projects 384 and 386 (Battalion Headquarters and Classroom Buildings, respectively, at Fort Riley, KS). The construction sites are visited weekly to observe and document the construction and quality management procedures being used. Virtually all phases of construction, from contracting to transfer of the finished facility, will be monitored to identify problems with delivering energy-effective facilities.

Construction on the projects began in April 1984, but progress has been very slow. The original construction contractor defaulted, and a new contractor has been selected. Thus, little progress has been made to date beyond the foundation work. Results of the monitoring will be available after completion of the projects.

6 CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the U.S. Army Corps of Engineers generally delivers high-quality facilities through the MCA construction process. However, facility quality could be improved, particularly in the area of energy efficiency, with changes to the construction phase of the building delivery system. The following specific areas have been identified as needing improvement. Suggested recommendations for implementing improvements are provided for each area and are based on the work completed to date. Final recommendations will be made when the research is complete.

1. While the current CQC/QA system has a sound basis, its operation needs improvement. The current process is very difficult for the Area/Resident Offices to implement, because it is not a part of the formal Corps organization. Thus, the Corps CQC/QA process needs renewed emphasis from high-level management to ensure that all participants understand the importance of quality construction.

2. The Area/Resident Offices are minimally staffed for implementing the CQC/QA system, and the technical knowledge required by the Corps QA field inspectors is increasing rapidly. Therefore, there should be major improvements in staffing and training field personnel if the Corps CQC/QA process is to be effective in producing energy-efficient facilities.

3. Corps of Engineers Guide Specifications generally do not provide sufficient requirements for inspection and acceptance testing to ensure that the finished product is energy-efficient. These specifications should be revised to include detailed inspection and acceptance testing procedures. CEGS-15805 should be revised as detailed on pp 21-23.

4. At times it is difficult to adhere to project specifications and CQC/QA procedures by the Corps' staff and by the construction contractor. As a result, the specifications' provisions for material quality, construction procedures, and acceptance tests cannot always be strictly enforced. Thus, these provisions must be enforceable and must be strictly enforced if the complex building design features required to achieve energy-efficient facilities are to be implemented in the actual facilities.

APPENDIX A:

FIELD OPERATING AGENCY RESPONDENTS

U.S. Army Engineering District, New York
New York, NY

New Jersey Area Office
Wrightstown, NJ

U.S. Army Engineering District, Baltimore
Baltimore, MD

Aberdeen Area Office
Aberdeen Proving Grounds, MD

Capital Area Office
Fort Belvoir, VA

Fort Meade Area Office
Fort Meade, MD

U.S. Army Engineering District, Louisville
Louisville, KY

Wright-Patterson Area Office
Dayton, OH

Fort Harrison Area Office
Fort Harrison, IN

U.S. Army Engineering District, Fort Worth
Fort Worth, TX

Eastern Area Office
Shreveport, LA

Southwestern Area Office
White Sands Missile Range, NM

U.S. Army Engineering District, Los Angeles
Los Angeles, CA

APPENDIX B:

SUGGESTED REVISIONS TO SECTION 19 OF CEGS-15805

19. TESTING, ADJUSTING, AND BALANCING

19.1 TESTING, ADJUSTING, AND BALANCING: TAB shall be performed by firms certified by the Associated Air Balance Council, the National Environmental Balancing Bureau, or by firms qualifying in compliance with the paragraph on performance.

19.2 PERFORMANCE: Performance of this work by firms specializing in the testing, adjusting, and balancing of heating, ventilating, and air-conditioning systems will be acceptable provided that adequate documentation attesting to the testing firms' competence has been submitted to and approved by the contracting officer. The testing firm shall have on its staff a registered professional engineer certified by NEBB or AABC who shall be responsible for the accuracy of the balancing procedure and test data. Firms shall provide proof of having successfully completed a minimum of five projects of similar size and scope.

19.3 PROCEDURE: Testing, adjusting, and balancing shall be performed in accordance with "AABC National Standards for Field Measurements and Instrumentation - Total Systems Balance" or "NEBB Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems" using approved field instruments specified, and rendering a concise, certified report of results.

19.4 FIELD TESTS: The proposed testing program shall be submitted to the contracting officer at least two weeks prior to the scheduled test to assure agreement as to personnel and instrumentation required and the scope of the testing program. Tests shall be conducted in the presence of the contracting officer who shall be given two days notice before any test is to be conducted. Water and electricity required for the tests will be furnished by the Government. Any material, equipment, instruments, and personnel required for the tests shall be provided by the testing, adjusting, and balancing firm.

19.4.1 Piping: After cleaning, water piping shall be hydrostatically tested at a pressure equal to 150 percent of the total system operating pressure for a period of time sufficient to inspect every joint in the system and in no case less than two hours. No loss of pressure will be allowed. Leaks found during tests shall be repaired by rewelding or replacing pipe or fittings. Calking of joints will not be permitted. Concealed and insulated piping shall be tested in place before covering or concealing.

19.4.2 Low Pressure Ductwork: All ductwork shall be leak tested in accordance with "SMACNA, Balancing and Adjustment of Air Distribution Systems." A maximum leakage of five percent of the system operating air flow at the static pressure indicated is allowed before covering with insulation or concealing in masonry. Duct shall be constructed and joints shall be sealed as described in "SMACNA Low Pressure Duct Construction Standards."

19.4.3 High Pressure Ductwork: All ductwork shall be tested in accordance with "SMACNA High Pressure Duct Construction Standards." This would include sealing of joints, hanging and supporting systems, testing of leakage, structural testing, and joint performance, etc.

19.5 CLEANING AND ADJUSTING: Pipes shall be cleaned free of scale and thoroughly flushed of all foreign matter. A temporary bypass shall be provided for all water coils to prevent flushing water from passing through coils. Strainers and valves shall be thoroughly cleaned. Prior to testing and balancing, air shall be removed from all water systems by operating the air vents. Temporary measures, such as piping the overflow from vents to a collecting vessel, shall be taken to avoid water damage during the venting process. Air vents shall be plugged or capped after the system has been vented. Inside of room fan-coil units, coil-induction units, air terminal units, and unit ventilator, the ducts, plenums, and casing shall be thoroughly cleaned of all debris and blown free of all small particles of rubbish and dust and then shall be vacuum cleaned before installing outlet faces. Equipment shall be wiped clean, with all traces of oil, dust, dirt, or paint spots removed. Temporary filters shall be provided for all fans that are operated during construction, and new filters shall be installed after all construction dirt has been removed from the building, and the ducts, plenum, casings, and other items specified have been vacuum cleaned. System shall be maintained in this clean condition until final acceptance. Bearings shall be properly lubricated with oil or grease as recommended by the manufacturer. Belts shall be tightened to proper tension. Control valves and other miscellaneous equipment requiring adjustment shall be adjusted to setting indicated or directed. Fans shall be adjusted to the speed indicated by the manufacturer to meet specified conditions.

19.6 PERFORMANCE TESTS: After cleaning, adjusting, and testing are completed as specified, each system shall be tested as a whole to see that all items perform as integral parts of the system and temperatures and conditions are evenly controlled throughout the building. Corrections and adjustments shall be made as necessary to produce the conditions indicated or specified. Capacity tests and general operating tests shall be conducted by an experienced engineer. Tests shall cover a period of not less than ... days for each system and shall demonstrate that the entire system is functioning in accordance with the specifications. Spot checks on the system are to to be made prior to the end of one year by the Corps as part of the post completion inspection. Equipment such as supply outlets, control valves, volume dampers, expansion valves, etc., should be checked thoroughly.

19.7 TESTING AND BALANCING PREPARATION:

19.7.1 Verify system is installed per original design, including modifications, before building is closed in. Modifications would include approved change orders and value engineering. This information can be obtained from the Corps of Engineers and the mechanical contractor.

19.7.2 Prepare a workable schematic layout of each HVAC duct system including any changes made during construction. Where there is more than one system, make a separate layout for each floor or each system. All dampers, regulating devices, terminal units, supply outlets, and return and exhaust inlets should be shown. Also show sizes, velocities, and flow criteria for main and branch circuits or ducts which are to be met. Include the air intakes and exhaust air and relief air louvers. Number all outlets for identification. This schematic must accompany the balance report submittals.

19.7.3 Prepare a similar schematic for piping systems indicating locations of expansion tanks, relief valves, pressure reducing valves, and flow control devices. This must accompany the balance report submittals.

19.7.4 Analyze the systems and data. Refer to "NEBB, Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems" for a list of items which must

be checked. From this list determine the best testing and balancing approach. Provide a report of all findings and TAB approach to the field engineer.

19.8 AIR DISTRIBUTION SYSTEM EQUIPMENT INSPECTION.

19.8.1 A checklist of all equipment to be checked is provided in "NEBB Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems." The following lists are to be used as guidelines in determining proper equipment performance.

19.8.2 Fans:

1. Verify the equipment matches the test report such as model number, make, arrangement, class, etc.

2. Verify all parts are functioning properly. (Refer to NEBB for all integral parts to be checked.)

3. Locate all start-stop disconnect switches, electrical interlocks, and motor starters. Motor starters must be equipped with thermal overload protection of the proper size according to the manufacturer's recommendations, and must satisfy requirements of the National Electrical Code.

4. Check availability of electrical power to all equipment needed for TAB work and verify the compatibility of voltage and phase.

5. Verify amperes and horsepower. Also, verification of power factor must be made in order to determine exact kilowatt consumption.

6. Inspect the fan inlet and discharge of fan plenums for obstructions. Closed dampers can cause plenum and ductwork failure or collapse.

7. Confirm air filter size, type, number, and condition of filters to be used for the TAB work. If high-efficiency filters are used, check to see that the filter frames are sealed to the plenum or duct to prevent leakage.

8. Set RPM per design.

19.8.3 Air Conditioning Units:

1. Generally follow the fan checklist.

2. Check the airflow pattern from the outside air intake louver and return air/exhaust air damper to the fan discharge.

3. Inspect the ducts and plenums for obstructions and foreign objects.

4. Confirm filter sizes, types, number, and installation.

5. Check cooling and heating coils for proper installation and heat exchange position (counterflow, parallel flow, etc.).

6. Check and set all automatic control dampers as required.

7. Confirm that duct system connections have been made to the proper units and follow the correct flow patterns.

19.8.4 Duct System:

1. Check that all outside air intake, return, and exhaust air dampers are in the proper position and operable for TAB work.

2. Confirm that all system volume dampers and fire dampers have been installed, are in the full open position, and are accessible.

3. Verify that all air terminals and terminal units have been installed and that terminal dampers are fully open.

4. Inspect duct systems for proper construction, and make sure that all turning vanes have been installed and that all joints have been sealed as specified.

19.8.5 Architectural Requirements:

1. Verify windows are installed properly and closed.

2. Verify that doors are closed.

3. Verify ceiling plenums are installed and sealed.

4. Confirm access doors are closed and tight.

5. Confirm air shafts and openings are as required.

19.9 HYDRONIC DISTRIBUTION SYSTEM EQUIPMENT INSPECTION:

19.9.1 Pumps:

1. Verify that equipment matches the test report data, such as model number, make, type, rpm, etc.

2. Verify that all parts are operating properly. (Refer to NEBB for all integral parts to be checked.)

3. Check availability of electrical power to all equipment needed for TAB work and verify the compatibility of voltage and phase.

4. Verify amps and horsepower. Verification of power factor must be made to determine exact kilowatt consumption.

5. Check system temperature and pressure combinations at pump inlets for possible flashing or cavitation problems.

6. Verify that makeup water pressure is per design.

19.9.2 Boilers:

1. Verify that boilers have been started and tested for proper and safe operation in accordance with the manufacturer's instructions and that all safety and operating controls have been tested, adjusted, and set for the proper operation.

2. Locate and confirm that all combustion air openings and barometric or draft control dampers for the boilers are of the proper size for the fuel being used.

3. Confirm that all boiler equipment, motors, pumps, and boiler feedwater equipment are operating properly.

4. Confirm proper settings and types of all operational and safety control devices, both for temperature and pressure.

5. Check for proper location and correct piping to air vents, air elimination fittings, and compression tanks.

6. Verify that water levels of steam boilers are steady and that the boilers have been properly flushed and/or "blown down."

7. Verify boiler nameplate data and add missing information (such as serial numbers, etc.) to the test report forms.

19.9.3 Coils:

1. Verify size and physical data.

2. Verify proper piping methods, connections for flow, pipe sizes, venting devices, etc.

3. Verify air flow directions.

4. Check to see that coil is placed in proper direction.

5. Confirm operation of control valve.

6. Confirm operation, type, and size of automatic valve, expansion valves, and other control equipment. (Temperature control valves usually are set for full flow during TAB procedures.)

19.9.4 Direct Expansion Coil:

1. Verify operation flow direction.

2. Verify operation of expansion valve.

3. Verify refrigeration flow by a sight glass.

19.10 HUMIDIFICATION EQUIPMENT:

1. Verify size and physical data.

2. Verify that humidifier is located in proper location in both steam and water systems.

3. Verify that humidifier discharge is in the proper direction in both steam and water systems.

4. Verify that components are working properly.

5. Verify that humidistat is in the proper location in airstream.

19.11 AIR SYSTEM TAB PROCEDURES: This section will frequently refer to two sources: "NEBB, Procedural Standards for Testing, Adjusting and Balancing of Environmental Systems" and "AABC, National Standards."

19.11.1 Basic Air System Procedures: Confirm that preliminary procedures have been completed and that checklists and schematic layouts have been prepared. Refer to NEBB, section V, A, 1-12, for basic procedures.

19.11.2 Supply Air System Procedures: Refer to NEBB, section V, B, 1-11, or AABC, section IV, chapter 17, for specified procedures.

19.11.3 Exhaust and Return Air Systems: Refer to NEBB, section V, C, 1-12, or AABC, Section VI, chapter 21.

19.11.4 Systems With Economizers: Refer to NEBB, Section V, D.

19.12 SPECIFIC AIR SYSTEM PROCEDURES:

19.12.1 Dual Duct and Single Duct Constant Volume Systems: Refer to NEBB, section VI, A, 1-8, or AABC, section IV, chapter 19.

19.12.2 Variable Air Volume Systems; Pressure Independent and Pressure Dependent: Refer to NEBB, section VI, B1, A-K, B2, A-G; or AABC section IV, chapter 20.

19.12.3 Induction Systems: Refer to NEBB, section VI, C, 1-7; or AABC, section IV, chapter 19.

19.12.4 Multizone Systems: Refer to NEBB, section VI, 0, 1-5; or AABC, section IV, chapter 18.

19.12.5 Systems with Hoods: Refer to NEBB, section VI, E, 1-4, or AABC, section IV, chapter 23.

19.13 HYDRONIC SYSTEM TAB PROCEDURES.

19.13.1 Basic Hydronic System Procedures: Refer to NEBB, section VII, A, a-u, or AABC, section IV, chapter 22.

19.14 SPECIFIC HYDRONIC SYSTEM PROCEDURES: All equipment such as boilers, chillers, compressors, etc., shall be started by, and operated under, the supervision of the responsible contractor or the designated authority.

19.14.1 Chilled and/or Hot Water Systems: Refer to NEBB, section VII BI(a-c).

19.14.2 Condenser Water/Cooling Tower Systems: Refer to NEBB, section VII, B2(a-r), or AABC, section IV, chapter 23.

19.14.3 Steam and Hot Water Boilers: Refer to NEBB, section VII, B3(a-i).

19.14.4 Heat Exchanger/Converter: Refer to NEBB, section VII, B4(a-i).

19.15 PUMP PERFORMANCE: To eliminate cavitation, it is necessary to maintain a minimum suction pressure at the inlet side of a pump. Available net positive suction head (NPSHA) must be greater than required net positive suction head (NPSHR) which is given in manufacturer's data. The equation for calculating NPSHA in an installed open system is:

$$\text{NPSHA} = P_A \pm P_S + \frac{V^2}{2_G} - P_{VP}$$

P_A = Atmospheric pressure (feet)

P_S = Gage pressure at pump suction, expressed in feet and corrected to the pump centerline. This value is positive if corrected gage pressure is positive and is negative if the corrected gage is a vacuum.

$V^2/2G$ = Velocity pressure at the point of measurement of PSG, (feet). V = velocity pressure in feet/minute. G = gravitational acceleration = 32.2 feet/second.

P_{VP} = Absolute vapor pressure of the fluid at pumping temperature (feet).

The NPSHA in a closed loop is simply the discharge head capability of the pump minus the piping friction.

Notes:

1. If NPSHA is less than NPSHR, this can be corrected by:

   a. Raising system pressure

   b. Lowering system temperature

   c. Lowering pump

   d. Throttling discharge side

2. NPSHA should always be determined for proper pump performance.

19.16 SOUND:

Manufacturer's data for sound levels of given equipment and diffusers are obtained in a controlled environment; the equipment will not perform the same way in a field installation due to absorption characteristics of the room, air movement, etc. The determining factor for sound levels will be the comfort of the occupant and the noise criteria for that particular space function. See relevant material for acceptable decibel levels in different applications. Sound levels can be measured by a decibel meter.

19.17 FILTER PERFORMANCE:

Manufacturer's data on filtration effects are obtained in a controlled environment and will not be the same when taken in a field installation due to air turbulence generated as a result of the design, area of filter that is in contact with the air, etc. Therefore, only in extreme cases will air purity be measured in the field.

19.18 REPORT FORMS:

Since systems are to be balanced under NEBB and AABC standards, corresponding test report forms shall also be used. The design engineer is responsible for designating specific forms to be used.

Note: NEBB has obtained a copyright for their TAB report forms. These forms may not be reproduced by nonmembers or noncertified TAB contractors. Certified NEBB contractors may apply to the NEBB national office to request permission to reprint or reproduce the forms.

19.19 EQUIPMENT EFFICIENCIES.

All measurements or readings used to calculate efficiencies must be taken instantaneously.

19.19.1 Fans.

1. After the system has been balanced, measure static pressure (P_S), total pressure (P_T) in inches of water, and flow rate (cfm) at diffuser.
2. By measuring P_S and P_T, total air horsepower (AHP_T) and static air horsepower (AHP_S) can be calculated.

$$AHP_T = \frac{CFM \times P_T}{6356} \qquad AHP_S = \frac{CFM \times P_S}{6356}$$

Both equations are based on the following:

$$HP = \frac{\text{cu ft /min} \times (\text{in. water}) \times \dfrac{14.7 \text{ lb/sq in.}}{407.1 \text{ in. water}} \times (144 \text{ sq in. /sq ft})}{33000 \text{ ft - lb/min/hp}}$$

Note: 14.7 pounds/inch is atmospheric pressure at sea level. Adjust value accordingly.

Altitude Above Sea Level	Atm. Press. in Pounds/Square Inch
0	14.7
1000	14.2
2000	13.6
3000	13.1
4000	12.6
5000	12.1
6000	11.7
7000	11.2
8000	10.8

Note: Pitot tube measurements should be taken where the duct is straight. The readings are usually taken at no less than 7 1/2 diameters from fan connection outlet. When using a straightener, the use of six duct diameters is recommended from fan outlet connection to outlet side of straightener and 1 1/2 diameters between the straightener and the tip of the pitot tube facing the flow.

3. With these same measurements and the fan speed for an extra check, it is possible to determine required brake horsepower from manufacturer's data if the measurements correspond to a point in the tables.

4. Fan efficiency is then:

$$\text{Total Eff.} = \frac{AHP_T}{BHP} \qquad \text{Static Eff.} = \frac{AHP_S}{BHP}$$

5. By measuring electrical input, it will be possible to check the results obtained above. Electrical power factor and motor efficiency must be taken into account.

19.19.2 Pumps. If the manufacturer's data on pump curves show values for efficiency, the following procedure need not be followed. If not, use of this procedure can determine an accurate value for the pump efficiency.

1. Measure GPM flow.
2. Determine total feet of head on pump.
3. Calculate water horsepower (WHP).

$$WHP = \frac{\text{GPM x feet of head x specific gravity}}{3960}$$

Note: Feet of head equals static plus velocity head at the pump suction subtracted from the static plus velocity head at pump discharge. Place gages on suction and discharge side at same elevation. Locate pressure gages as close to pump flanges as possible. It is recommended that a piping configuration be used that uses the same pressure gage to measure the pump suction pressure and discharge pressure.

Note: Specific gravity of water equals 1. If any other fluid is used, it must be measured at or corrected to approximately 62 degrees F.

$$HP = \frac{1}{3960} = \frac{\text{GPM x ft head x 8.33(lb/gal) water x SG(lb liq./lb water)}}{\text{33000 ft lb/min/hp}}$$

4. Using values for feet of head and GPM, go to pump curve and determine brake horsepower.

5. Efficiency can then be calculated by:

$$EFF. = \frac{WHP}{BHP} \times 100$$

19.19.3 Chilled Water Coils; Constant Volume.

1. After system has been balanced, measure entering air dry bulb and wet bulb temperatures, and leaving air dry bulb and wet bulb temperatures. Measure CFM at coil inlet.

2. Measure GPM through coil, entering water temperature, and leaving water temperature.

3. Plot air temperatures on a psychrometric chart and find the change in grains of moisture per pound of dry air (Δg), and change in temperature (dry bulb), $(\Delta T)_S$.

4. Calculate the latent load. $(H_L) = 0.7 \times CFM \times \Delta g$.

5. Calculate the sensible load. $(H_S) = 1.08 \times CFM \times \Delta T_S$.

6. Calculate total capacity of coil.

$$BTUh = GPM \times 500 \times \Delta T$$

GPM = Gallons per minute through coil

500 = C_p x 60 minutes/hour x 8.33 pound/gallon = 500 (BTU minute/^{O}hour gal)

ΔT = Leaving water temperature - Entering water temperature

C_p = Specific heat = 1.0

7. $$EFF_{tot} = \frac{\text{Latent load (air) + Sensible load (air)}}{\text{Total capacity of chilled water coil (BTUh)}}$$

19.19.4 Chilled Water Coils: Variable Volume:

Same as constant volume, except take measurements at 100 percent flow and 50 percent flow to verify correct operation.

19.19.5 Direct Expansion Coils.

1. Measure entering air dry bulb and wet bulb temperatures when in mixed air condition.

2. Measure leaving air dry bulb and wet bulb temperatures. Also measure CFM and velocity in feet per minute.

3. Plot these values on a psychrometric chart and calculate change in grains of moisture per pound of dry air (Δg). Also calculate sensible change in temperature (ΔT_S).

4. Measure suction refrigerant temperature at coil. Determine number of rows in the coil and fin number. Find total BTUh extracted per design by consulting manufacturer's data.

5. Calculate sensible cooling load and latent cooling load by:

$$Q_S = 1.08 \times CFM \times \Delta T_S$$

$$Q_L = 0.7 \times CFM \times \Delta g$$

Notes:

1. $1.08 = C_p \times 60$ minutes/hour x 0.075 pounds/cubic foot

2. Specific heat (C_p) for air = 0.24 btu/pound ^{O}F at 14.7 psia. For elevations other than sea level, adjust C_p accordingly.

3. 0.7 = 0.075 pounds air/cubic foot x 1100 BTU/pound water x (1 pound water/7000 grains)

   x 60 minutes/hour

4. Enthalpy for water temperatures from 85^{O} - 93^{O} can be taken as 1100 BTU/pound water; for other temperatures consult the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).

6. Compute total cooling load.

$$Q_{T\ actual} = Q_S + Q_L$$

7. Calculate efficiency:

$$EFF_{tot} = \frac{Q_{T\ actual}}{\text{Tot. BTUh per Manufacturer's data}}$$

19.19.6 Hot Water Coils.

1. Measure entering air dry bulb and wet bulb temperatures.
2. Measure leaving air dry bulb and wet bulb temperatures.
3. Measure CFM.
4. Plot these temperatures on a psychrometric chart and calculate $\Delta T_{sens.}$
5. Calculate sensible load:

$$Q_{sens.} = 1.08 \times CFM \times \Delta T_{sens.}$$

6. Measure GPM through coil, entering water temperature (EWT), and leaving water temperature (LWT).

7. Calculate total capacity of coil:

$$BTUh = GPM \times 500 \times \Delta T$$

Note: ΔT = EWT - LWT

8. Find coil efficiency:

$$EFF = \frac{\text{Sensible Load } (Q_{sens})}{\text{Total Capacity (BTUh)}}$$

19.19.7 Steam Coils. Efficiency would have to be calculated over an extended period of perhaps one hour. Dry bulb and wet bulb temperatures at the inlet would have to be measured constantly. A condensate meter would also have to be used to establish data for calculating BTUh input. This process would be somewhat uneconomical because of the equipment cost and time factor.

19.19.8 Electric heaters. Measure amps and volts with an ampmeter and voltmeter, respectively. Calculate KW consumption by $P(KW) = VI \times 10^{-3}$. Find total capacity by converting to BTUh input by 1 KW = 3412 BTUh. Sensible loads would be calculated in a similar manner to hot water coils.

$$EFF = \text{Sensible Load/Total Capacity}$$

19.19.9 Gas Heating:

1. Find total capacity using a cubic-feet-per-hour meter to measure the gas feed rate.

2. Calculate sensible loads in the same manner as hot water coils.

3. Find burner BTUh by multiplying gas feed rate (CFH) by heat content of gas in BTU/cubic foot. Verify heat content of gas with utility company.

Note: Derate at higher elevation by approximately 4% per 1000 feet.

4. Calculate efficiency by:

$$EFF = \text{Sensible Load/Burner BTUh}$$

Note: EFF can be improved with proper gas-air mixture. This is found by measuring stack temperature and chemical properties of the flue gas.

19.19.10 Chillers.

1. Measure the water temperature into the chiller and the water temperature out. Measure the GPM through chiller.

2. Calculate the total load on the chiller by BTUh = GPM x 500 x ΔT, where $\Delta T = T_{out} - T_{in}$.

3 Measure the amps and volts of the chiller. Account for the power factor when determining KW consumption.

4. Convert the total power supplied to BTUh by:

$$BTUh = \text{(Total Power)(3412 BTUh/KW)}$$

5. Find efficiency by:

$$EFF = \frac{\text{Total Load on Chiller (BTUh)}}{\text{Total Power Supplied (BTUh)}}$$

6. If the overall refrigerant system efficiency is desired, add the power input from the chiller, compressor, condensate pump, cooling tower fan, and cooling tower

pump together and replace this value with the value obtained in step 4. Follow the same procedure in calculating efficiency.

19.19.11 Cooling Towers.

1. Measure the entering water temperature, leaving water temperature, and GPM flow.

2. Calculate total load by BTUh = GPM x 500 x ΔT.

3. Measure the amps and volts of all equipment that provides power to the cooling tower. This would be the pump and fan.

4. Find the power input of each piece of equipment by:

$$P(KW) = VI \times 10^{-3}$$

5. Add up the power input of each piece of equipment to find the total power supplied to the system.

6. Convert the total power supplied to BTUh by:

$$BTUh = (\text{Total Power})(3412\ BTUh/KW)$$

7. Find efficiency by:

$$EFF = \frac{\text{Total Load}}{\text{Total Power}}$$

Note: Consult manufacturer's data because efficiency varies with ambient temperature.

19.19.12 Humidifiers.

1. Measure entering mixed air wet bulb and dry bulb conditions at inlet side of humidifier.

2. Measure leaving air wet bulb and dry bulb conditions at most remote diffuser. Also measure CFM supplied to room.

3. Plot mixed air conditions and room design conditions (generally dry bulb and relative humidity) on a psychrometric chart.

4. Determine the number of grains/lb of dry air that need to be added to maintain design room conditions.

5. On same psychrometric chart, plot mixed air conditions from step 3 and actual conditions leaving the diffuser.

6. Determine the number of grains/lb of dry air that have been added to the system.

7. Calculate pounds (water)/hour added for design conditions by:

$$G\ (\text{lb water/hr}) = \frac{60\ \text{min/hr} \times \text{CFM (design)} \times \Delta g\ (\text{grains})/\text{lb air}}{13.33\ \text{cu ft/lb} \times 7000\ \text{grains/lb air}}$$

$$G\ (\text{lb water/hr})_{des} = 4.5\ (\text{min}\cdot\text{lb/hr}\cdot\text{cu ft}) \times CFM_{des} \times (\Delta g_{des}/7000)$$

8. Calculate pounds (water)/hour added for actual conditions:

$$G\ (\text{lb water/hr})_{act} = 4.5\ (\text{min.lb/hr cu ft}) \times CFM_{act} \times (\Delta g_{act}/7000)$$

9. Calculate efficiency by:

$$EFF = \frac{G\ (\text{lb water/hr})_{act}}{G\ (\text{lb water/hr})_{des}} \times 100$$

APPENDIX C:

SUGGESTED REVISIONS TO CEGS-15805, AIR SUPPLY AND DISTRIBUTION

The following are general suggested improvements to CEGS-15805:

1. The specification should include a section on humidification equipment.

2. A statement should be made in reference to "Systems Operation Demonstration." Upon completion and prior to acceptance of the installation, the contractor shall subject systems to such operating tests as are required to demonstrate that the equipment installed will operate within the specified limits through normal ranges and sequences and simulation of possible abnormal conditions. Every device shall be caused to function, manually and automatically, in accordance with its purpose. Operating test duration shall be for not less than [....] hours after all major connections have been made. If tests do not demonstrate satisfactory system performance, deficiencies shall be corrected and system shall be retested. The engineer shall specify which tests are to be performed.

3. Any statements that the contractor must do any designing, such as supports, leakage characteristics, etc., should not be in the specification, since it causes a conflict between the design firm and the contractor. Many contractors do not have personnel who are qualified to design supports. Mechanical contractors also are not normally familiar with the overall structural plan, and are not in a position to know where to install hangers. Problems can also arise in assigning responsibility for the design once modifications are made as to whether the designer or the contractor is ultimately responsible.

The following are specific suggested improvements to CEGS-15805:

1. Section [2.] - A provision similar to the following should be made: "Because of the small scale of the drawings, it is not possible to indicate all offsets, fittings, and accessories that may be required. The contractor shall carefully investigate the plumbing, fire protection, electrical, structural, and finish conditions that would affect the work to be performed and shall arrange such work accordingly, furnishing required ductwork offsets, fittings, and accessories to meet such conditions." This statement helps to prevent the contractor from demanding additional money through change orders because offsets, etc. had to be made, because they were not indicated on the drawings.

2. Section [3.1] - In cases where shop drawings are required, architectural engineering firms and field engineers should verify them by consulting an applicable Sheet Metal and Air Conditioning Contractors National Association (SMACNA) standard. When referring to SMACNA, the architectural engineering firm will identify the applicable manual for the design. Shop drawings should not be too complicated because of the verification problems. In referring to the existing guide specification, it seems unrealistic to expect a mechanical contractor to determine the "loads imposed on each support or anchor." This portion could possibly be omitted.

3. A statement telling who should provide safety disconnect switches, contactors, motor control starters, etc. should be included. The engineer should specifically

state whether equipment is within the motor control center or remote. Also electrical contractors should check electrical data and wiring diagrams received from the mechanical contractor for compliance with project voltages, wiring, controls, and protective devices shown on electrical plans.

4. Section [8.] - This section states that ductwork shall comply with "SMACNA, Low Pressure and High Pressure Duct Construction Standards", and repeats the SMACNA requirements in the following sentences. Unless the requirements are going to differ from SMACNA, there is no need to list them again.

5. Section [8.1.4] - This section is often modified or deleted in most other government project specifications. It contains some discontinuity, thus requiring that it be omitted or rewritten.

6. Section [8.9.1] - This section should be re-titled "plenums and casings and drain pans," since the paragraph seems to address the subject of drain pans most often.

7. Section [9.2.3] - A specific vacuum breaker should be specified in this section or in the Materials and Equipment section.

8. Section [13.] - There should be a section on sequence of control outlined in the "Temperature Controls" section.

9. Section [13.] - This section should be a separate entity under the "Mechanical" division and should encompass all mechanical systems. This would make the information more readable and allow better coordination between divisions. Conflicts seem to occur when referrals and re-referrals are required.

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